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Published in:
Proceedings of the 14th European Conference on e-Learning (ECEL 2015)

Publication date:
2015

Document Version
Peer reviewed version

Individualized Learning Through Non-linear use of Learning Objects – With Examples From Math and Stat

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Abstract:
Our aim is to ensure individualized learning that is fun, inspiring and innovative. We believe that when you enjoy, your brain will open up and learning will be easier and more effective. The methods use a non-linear learning environment based on self-contained learning objects which are pieced together by a Hyperbolic Graph, or by the students themselves. This learning system makes it easy for students to find a path through the course material which suits his/her personal learning style and which makes learning more motivating, and efficient, and which leads to better learning. The methods have been tested in two case studies. One was a continuing education course in statistics for a global medical company, and the other was a "big" - both in terms of the number of students and in the number of ECTS points - introductory course in mathematics at a major technical university. The continuing education course made it possible for the company's employees, from many different parts of the company and from all around the world, to learn from the same course. For the university course we started with a pilot project where our methods were used during only one course week. The pilot was a success and we then used the experiences from it to reshape the entire course. This course has now been running for 5 years and consistently receives very good evaluations, both from students and teachers. A clear finding from the test cases is that our learning method creates more motivation and makes the students use more time on the course and prepare better for the lectures. An important discussing point is how much "free choice" is best for the learners. We believe that the possibility to follow your own learning style by choosing between different types of material is important and ensures better learning and more motivation for all students, and that for the best students it also gives courage to go beyond the curriculum.

Keywords: individual learning, learning objects, non-linear learning, Hyperbolic Graph, continuing education course, university mathematics course

1. Introduction

People have different learning styles, i.e. different favorite approaches to learning new topics. If you as a teacher can create learning material which the student can make match her individual learning style, she will learn faster and more smoothly. Coming from high school, students have different prior knowledge, different ways of learning, and different goals. During their time at university their knowledge and skills diverge even more. In Europe, the Bologna agreement leads to greater mobility and introduces still more diversity. Our methods are aimed at overcoming these two barriers to efficient learning: different learning styles and different prior knowledge.

We create a non-linear web-based learning environment by combining learning objects that contain the individual components of the course in a Hyperbolic Graph which provides overview. "Learning objects" can be defined as self-contained "somethings" designed for learning. They are essential for non-linear learning and provide an efficient way of producing reusable course material. To connect the learning objects in a meaningful way we think of the Hyperbolic Graph – ever changing and adapting to one's current objectives and perspective. The Hyperbolic Graph is the metaphor for this way of learning, and sometimes also the implementation of it.

Non-linear means that you can study topics in the order you want and choose between different presentations of the same topic – e.g. a video at an elementary level, a "speak" explaining the applicability of the methods, or an app explaining a part of the theory. Different learning styles means that some users will look at examples first and afterwards learn which theories they are based on. Others will do it in the reverse order. Some will work with problems first, then look at pictures that illustrate the essential parts, and finally read a text or listen to a spoken explanation. Only your imagination sets the limit.

Our aim is to ensure individualized learning that is fun, inspiring and innovative which leads to more efficient and better learning. Our method enables students to meet challenges posed by different learning styles and prior knowledge by letting them design courses to fit their individual needs.

Even if one uses “modern” learning techniques, such as problem based learning or team based education, more has to be done to build learning environments that are good for all students and make individualized learning easy. Courses should make room for the ways students like to learn and adapt to what they already know. If a student’s level is high she should study more advanced material – and thus put together a different course than a student who starts from a lower level. With new generations of students grown up with computers learning should be – at least a little – like a game.
Learning objects are an important possibility to achieve all of this. The literature about learning objects is concentrated to the early 2000, but little information about how they have fared in practice is available, see also Sek et al. (2012). Much of the literature concentrate on how to store and maximize the reusability of learning objects, see e.g. Muzio et al. (2002). Time is ripe to report the practical experiences from using learning objects that now are becoming available.

In this paper we discuss these ideas and share our experiences from using them in a continuing education course and in a university course. Have you ever tried to participate in a continuing education course where you were either too good, or where you did not have the skills needed? It is boring and unproductive - and you do not learn. This is the reason we based the continuing education course in statistics on non-linear learning. The course was designed for a global medical company and had participants from many different parts of the worlds and different time-zones, and was hence not only a course that used e-learning, but also a global distance learning course. Further, the course environment had to make it possible to learn in many different situations, perhaps as in Figure 1.
How should one meet the students in this situation? This gave even more to think about.

Based on the experiences from this course we redesigned the introductory mathematics course at the Technical University of Denmark using the ideas of learning objects, and by combining them with lectures and group work.

Figure 1: Web learning can be done in many environments.

2. Entering a New Universe

Visualize yourself entering a course on the web...The first image that meets you is a map – or rather a Hyperbolic Graph. It contains small “worlds” (learning objects) spread around in “space” and organized in “galaxies”. Each galaxy corresponds to a part of the course, or to “How to use the system”, or to “Exam” or to….. You can click on a part of the map and that part will be enlarged to make navigation in it easier and to show the worlds from a different perspective. You can fly around and by clicking enter the worlds you want to. You can stay in a world as long as you like and visit it as many times as you want. Perhaps you will start with a quiz. If it shows that you already know that world you can leave it and go to a new one. Otherwise you stay and maybe watch a video, play a game, read an article or try your skills on an example. If you think the world is a little too tough there will be another one teaching the same topic in an easier way. Do you need information from another world? There is a “Google” search system to help you. Just fly around and try…

To implement these ideas we have developed a system called HEROS (Higher Education Reusable Objects in Statistics) which includes the Hyperbolic Graph. Figure 2 gives an example of what this can look like. HEROS is used to manage the continuing education course where our ideas are tried out.
The entire continuing education course was centered at the Hyperbolic Graph. It was the only way for the learners to find their ways between the learning objects and to choose which object to work with next.

A more "basic" way of using these ideas is to provide all the material without using the Hyperbolic Graph, but perhaps grouping all videos, all quizzes, all examples, …, and then simply letting the students themselves select the type of material which suits their own learning style, and order it the way which suits them best. This principle was used in the university course.

3. Individual Needs

What do we mean by different learning styles? "Most people of college age and older are visual, while most college teaching is verbal - the information presented is predominantly auditory (lecturing) or a visual presentation of auditory information" (Felder and Silverman,1988). This states the problem very clearly. In standard university courses we typically explain each topic once and in one way. However, we learn in different ways, and students like to have the possibility to learn in their favorite way. They don't want to waste their time on something which is not optimal for them.

Guarnieri and Meyer (2014) evaluated the learning resources provided in an online postgraduate course in applied statistics. In a survey of 57 of the students which followed the course 74 % selected more than one preferred learning style, with the "Doing" (75 %) learning style being most favored followed by Reading (63 %), Looking/Watching (42 %) and Hearing (37 %).

After having attended a continuing educations course you are often left with the feeling that what you learned was not quite what you need in your daily work, and when you listened things were either too complicated or too easy for you. In university courses we often teach for the middle group and students who need more preparation and students who think that it is all too easy and without challenges are left to themselves.

If we, as course providers, are to solve these problems we need to exploit the possibilities of the computer much more. Many books and papers discuss different ways to organize web learning, e.g. Davidson-Shivers and Rasmussen (2006), but we still need new ideas on how to use the computer not just as an electronic book, but in more challenging ways. This is what we do.

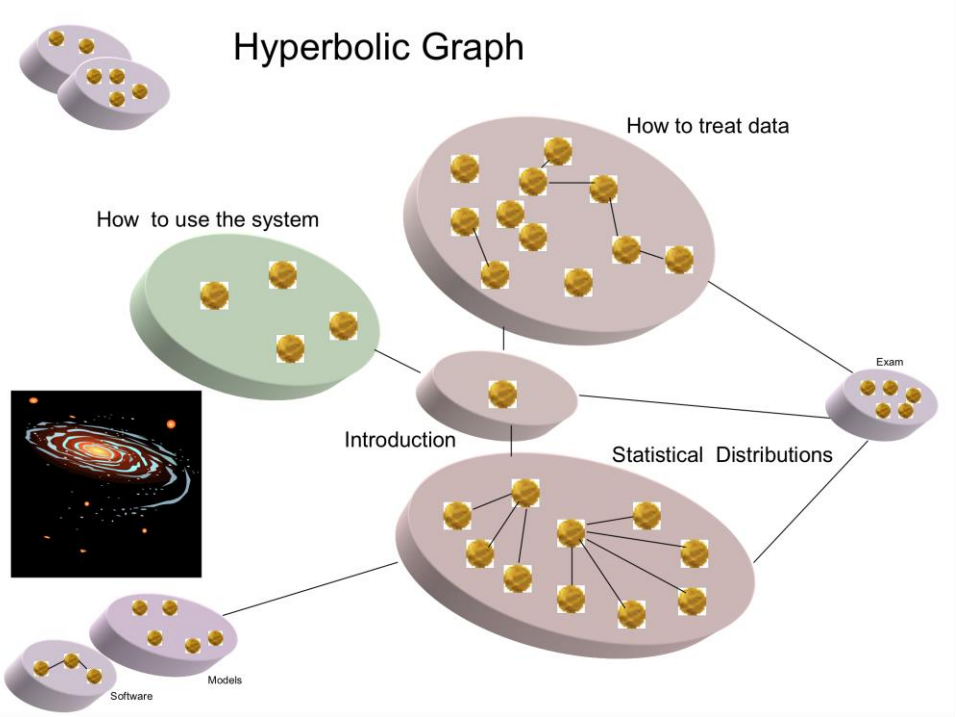

Figure 2: The middle of the Hyperbolic Graph shows what interests you right now – further away you can catch a glimpse of other areas that you will click on and expand later. The spheres are worlds (learning objects) and are collected in galaxies – e.g. "Introduction to the system" or "Statistical Distributions". Each student chooses

her own path between worlds, and may skip some completely. It is easy to go back and forth between worlds, and they can be visited in any order. The lines show connections between worlds or galaxies.

4. Learning Objects and Non-linear Learning

Usually learning/teaching is linear. You read a book trying to understand every little piece of information sequentially, beginning at page one, and ending at the last page, or you watch a lecture following the teacher's progression. But does it have to be so? Cognitive research shows that often we do not learn best in this way (Jensen, 2005). Instead learning could be non-linear: One grabs a little piece here and a little piece there – and in the end gets the whole picture. In non-linear learning based on learning objects topics can be "visited" in the order you like, and topics are presented using different media and on different theoretical levels, ranging from an intuitive description to a full explanation. For alternative approaches to non-linear learning see Robberecht (2007) and Morgan and Adams (2009).

A learning object can be defined as "any digital resource that can be reused to support learning" (Wiley, 2001). Either you build entirely new learning objects from scratch, or you take existing learning material – whatever it is – and divide it into suitable parts. In both cases the learning objects have to be made self-contained so they can be used in many orders. This is quite challenging. Further, it is "allowed" and desirable to explain the same topic using different techniques (figures, examples, text, video etc.), and on different levels. Hence, it is not just a question of cutting the material into pieces – like dividing a book into chapters – it is something quite different. It should be possible to use the learning objects in other courses in the future, so they should be "self-contained" and course specific material and software should be in their own learning objects – not mixed together with theory or general examples.

A major reason for working with learning objects is reusability. Learning objects are easy to modify and update (as opposed to writing a new book), and it is attractive to use learning objects made by others. They make the job as a teacher easier and more fun. An additional advantage is that students can design their own learning objects – maybe as an assignment – which then can be used in later courses.

5. A Continuing Education Course in Statistics

Our first course using these principles is an introductory course in statistics, produced for a global medical company. It is aimed at upgrading employees, with quite differing experiences from using statistics, and working all around the world. We have given the course 3 times, to around 40 students. The evaluations ranged from OK to very good and the exam – especially the oral part – showed that the students had learned a lot from the course.

In the middle world in the Hyperbolic Graph key persons from the company explain why the course is important both for the company and for its employees. The central course content is "Data" and "Statistical Distributions" – so these are the two main galaxies. We took pains to see to it that all elements that are needed for understanding really are there, and in a form which is as useful as possible for the learners. There is also an exam galaxy and a galaxy with an introduction to the system. The main galaxies each consist of 10-15 learning objects that all have an inspiration page telling in everyday words what it is all about, and a quiz. The exam uses material specific to the company and is divided into a "multiple choice" part and an oral part that is taken in groups. Starting with a real company problem, the groups make an oral presentation of their "solution", aimed at the CEO, a group leader, or a group of workers. The presentation is either face-to-face, or on the web for international learners.

In this first version of HEROS we use Lectora, an authoring tool made by Trivantis (http://www.trivantis.com), and Hypergraph (http://hypergraph.sourceforge.net) – a tool for making the Hyperbolic Graph.

6. An Introductory University Course in Mathematics

The first mathematics course at the Technical University of Denmark has around 1000 students and corresponds to 17.5 ECTS. It is a modern course with emphasis on Maple, a computer language for mathematical manipulation and visualization. The course functions quite well. The course covers major topics in linear algebra,

complex numbers, differential equations, Taylor series, integration, and topics in differential geometry. Pedagogical improvement is a central concern for the teachers. When some students asked for more overview and “non-linearity” we decided to try combining the non-linear use of learning objects with the existing course.

We first made a prototype for a new course by redesigning one week of the course. The idea was to try out lots of different material and ask the students what they thought was best. We kept the lectures and exercises and included a collection of web-based learning objects including modular e-notes covering the theoretical content (that would normally be presented in a linear way in a textbook), Maple demonstrations, exercises, video appetizers motivating and exemplifying topics, video recorded lectures, interactive visualizations in Maple, and multimedia pen casts (recorded voice and drawing/writing) that explain particular methods and give examples which show how to use the theory. The prototype was developed in the open source Content Management System (CMS) Typo3. We saw that using learning objects changed the students’ behavior in several ways. It gave them an option to choose material in an order that matched their learning styles, and it made it easy to prepare for lectures and prepare for exams. The making of the course is described in more details in May et al (2010) that was written after introducing one redesigned week in the course, but before implementation in the entire course. One conclusion was: "Some students found (the possibility to choose) learning styles useful, whereas others ignored this option by following a generic order of objects. Learning styles is a disputed concept”. This shows that not all students benefit from the possibility to adapt to different learning styles. And in May et al (2010) later on “it can be misused if teaching is adapted individually to these styles, since students need to develop skills characteristic of each type of learner in order to function effectively as future engineers. The pedagogical concern should be to support variation in teaching methods and variation in the presentation of content." A consistent attitude to learning styles across courses could make the students more aware of their preferences and make them more efficient learners.

The effect on diversity of prior knowledge is discussed in May et al (2010): "The challenge raised by the diversity of student’s prior knowledge and skills seems to be much more important to address in higher education and here adaptation based on online testing is more promising (Clark and Feldon, 2005). Learning objects can play an important role in harmonizing competence levels of students and in providing individualized assistance for students with deficient prior knowledge in specific areas. At DTU the web-based e-math was used after the ordinary lectures in the time slots assigned for computational exercises and other assignments, but e-math was also used by students to prepare for lectures and as repetition." Before the course was redesigned almost none of the students prepared for the lectures. This was one of the reasons why we decided to change the course: to make it easier for students to prepare by e.g. watching a video in the buss on their way to the university.

After this first phase of the project where just one week was redesigned we transformed the entire course by using the new principles and selecting the most used and best evaluated parts. These included all the above mentioned types of material, and these are now a part of the course. Pen casts and video recorded lectures are among the most popular among the students. An important idea was that we still took in ”too much” material, meaning that you as a student are not supposed to use it all.

Elements of web-based learning in a face-to-face course give the possibility to adapt to individual learning styles and levels in an elegant way. The course has been given for more than 5 years now. We have learnt a lot from experience and from feedback from students and teachers, and have continuously modified the course so that it now runs very well and is quite popular. Often courses "go back" to a more classical design after some years but we have managed to keep the new design, and when we change the content of the course we have kept the basic idea unchanged. The reason for this is that the students like the format of the course and learn well from it.

7. Discussion and Conclusions

When introducing a non-linear learning system natural questions are: How much order between learning objects is optimal? How much guidance on how to work with the course is best? In Wiley (2001) is argued: “…LEGO-type thinking that each and every learning object be compatible (or combinable) with every other learning object. This requirement is naïve and over-simplistic, and if enforced may keep learning objects from ever being instructionally useful” and “Let us try the atom as a new metaphor: An atom is a small “thing” that can be combined and recombined with other atoms to form larger “things””. This may be said with a linear course structure in mind but also reflects worry about “no structure” being equal to “no learning”.

Chiu and Churchill (2015) used learning objects in a secondary school algebra course. They write: "Mayer et al. (2009) conducted many experiments in different subjects and suggested 12 design principles for multimedia learning as guidelines for effectively presenting data or information through the two channels – audio and visual. These principles aim to avoid redundancy and help learners reduce cognitive overload to promote learning and thorough understanding, and enhance long-term memory". Chiu and Churchill (2015) base their work on 7 of these principles. This view, to avoid redundancy and to guide the students as much as possible through the learning process is very different from our view, where diversity and "too much material" to choose from is important. Baki and Cakiroglu (2010) instead talk about Rich Learning Environments. These are much more in line with our viewpoint.

Our courses use less structure and guidance than a usual "linear" course. In the continuing education course we only have the lines that connected the worlds or galaxies in the Hyperbolic Graph and the "google" search system. Clearly learners benefit from directions, but on the other hand, too much guidance can make it harder for them to find their own learning path. Before the course we had many questions like "Where do I begin?" but after the students had started working only one had a complaint about "missing structure". Perhaps "flying around" and finding your own way is a part of the learning itself. Of course some orders of visiting learning objects are better than others, it's just that the "best" order is different for different persons, and that finding it is – maybe – best done by the person herself.

"Empirical evidence indicates that not all of learners can benefit from hypermedia learning. In particular, they have problems to deal with non-linear learning" (Chen, 2002). The obvious answer to this is to prepare a guided tour for those who have problems with choosing freely. However, this could easily have the unwanted consequence that everybody would use the guided tour.

Our users at the university course state strengthened motivation as the most important outcome from using our learning system. This could be because the system makes it possible to adapt to individual learning styles and individual background knowledge in a better way. Tutors for the students report that they do not hear as many complaints as before about the course - instead the students seem happy with the learning process.

We found it difficult to measure the outcome of changing the university course. A "before" and "after" measurement was not possible because so much - also the curriculum - was changed during the process. In new studies it will be an important part to design ways of making unbiased measurements of the effects of the learning method.

In the continuing education course we tried to stay as close as possible to the definition of a learning object and made them as self-contained as we could. This was partly changed in the university course since the progression was given by the lectures and thus "self-containedness" was only maintained week by week.

Large flexibility may be most important for more experienced learners with clear goals. Instead less flexibility worked well in the university course which had a large curriculum and less experienced learners. We don't believe the university course would have benefitted from a larger flexibility. In evaluations based on grades, students in the middle group and below often show the largest improvements from using learning objects, see e.g. Sek et al., (2012). This doesn't necessarily mean that the benefit for good students is smaller -- they will just get high grades in almost any learning situation. But it is not only the grades that count, and for this group it is even more important to keep motivation up and use their full potential in the learning process. This is possible with our method.

Our experiences and results underline the importance of studying and developing non-linear learning. Non-linear learning may be the most natural way of learning, but only now, with modern computers, is it possible to implement. An advantage of our system is that it makes it easy to share learning material. As a teacher you can build your own course by creating some learning objects of your own and then mix them with objects made by others.

The ideas outlined in this paper are a piece in the puzzle to construct a new concept of learning. It can be used at any level from elementary school to university. We need more experimental work to understand the potential and limitations of the suggested framework better.

Acknowledgement
The Danish Ministry of Science, Technology and Innovation has supported the work with 3 million DKK. Part of this work has been done at a research visit to ETH Zurich. I want to thank Paul Embrechts for his hospitality during this visit, and an anonymous referee for interesting and useful comments which led to considerable improvements. I also want to thank all my colleagues and friends who have helped me with implementing and improving my ideas, and who have worked with developing the two courses.

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